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A' ~~Methods of Forming Copper-Containing Sputtering Targets~~  
~~COPPER SPUTTERING TARGET ASSEMBLY AND METHOD OF MAKING SAME~~

5 ~~A1~~ A2

# BACKGROUND OF THE INVENTION

Interconnects for use in integrated circuits are generally made of aluminum but aluminum is unsatisfactory in high speed semiconductor devices. The resistivity of aluminum as well as its electromigration limits and restrict its use in such applications. The present invention contemplates use of high purity copper as interconnects for use in integrated circuits which have requirements of line width about 0.18  $\mu\text{m}$  or less and are to be used in semiconductor devices at 1200 Mhz clock speeds. The interconnect lines are created by sputtering high purity copper from sputtering target assemblies.

To produce very small line widths, as described, we have determined that the sputtering target should be of high purity, i.e. at least 99.999 wt.% purity, (referred to as 5N copper) and preferably 99.9999 wt.% purity (referred to as 6N copper). Purity is important to maintain the low resistivity of the copper line so that high speed goals can be achieved. Moreover, purity may also influence electromigration resistance.

We have also determined that it is also desirable that the sputtering target have a fine and substantially uniform grain size, preferably about 50  $\mu\text{m}$  or less. The fine grain size aids in achieving a uniform film thickness during deposition, allows the target to sputter faster, and seems to result in fewer particle problems on the substrate, i.e. wafer. It is also important in accordance with the invention for the target to be diffusion bonded to a light weight, high strength backing plate. As targets become larger, particularly those designed for 300 mm diameter silicon wafers, the weight of the target becomes a significant handling factor. Technically, it would be possible to decrease the thickness of the sputtering target surface

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because only a part of the target is consumed. However, in order to take advantage of this capability, it is necessary to bond a thinner target blank onto a lightweight backing plate provided the thickness of the sputtering target surface does not allow the target assembly to warp during use. Warping of the target can lead to inconsistent deposition as well as particle generation. Therefore, it is important that the backing plate be strong and stiff in addition to being lightweight. The present invention achieves these objectives by providing a sputtering target assembly comprising high purity copper target diffusion bonded to a precipitation hardened aluminum backing plate. By use of diffusion bonding to join the target to the backing plate it is possible to avoid the need for soldering which is undesirable because temperatures required for sputtering often are sufficiently high to melt the solder bond of the targets and, moreover, the heat generated has potential to continue grain growth in the target after long periods of use.

#### SUMMARY OF THE INVENTION

In accordance with the invention there is provided a sputtering target assembly comprising a high purity copper target, a precipitation hardened aluminum alloy backing plate and an intermediate layer of CuCr diffusion bonded to the target and backing plate. Desirably, the aluminum is in the fully hard T6 condition and the sputtering target comprises copper of a purity of at least about 99.999 wt.%. The sputtering target also contains a micro-alloy grain stabilizers comprising at least one of Ag, Sn, Te, In, Mg, B, Bi, Sb, and P. The stabilizer is preferably present in an amount of about 0.3 ppm to 10 pmm. The intermediate CuCr comprises copper and about 0.5 to 1.5 wt.% Cr, preferably about 1%. The high purity copper target has a substantially uniform grain size of not more than about 50  $\mu\text{m}$ .

In another embodiment of the invention there is provided a method of making a sputtering target assembly which comprises providing high purity copper target of at least about 99.999 wt.% purity. Preparing a master alloy of copper and not more than about 10 ppm of at least one of the micro-alloy grain stabilizers described previously, preparing molten combination of high purity copper and the master alloy and solidifying the molten combination to produce a cast billet; hot deforming the cast billet for a total of at least about 50% deformation on each of the axes and then rapidly quenching the deformed billet, preferably in water; frictionless forging the quenched billet at elevated temperature to about 70% of the starting length of the billet and rapidly quenching preferably in water; cold rolling to a total of about 90% deformation; producing an aluminum alloy backing plate having a precladding surface of CuCr diffusion bonded thereto; diffusion bonding the high purity copper target to the preclad CuCr surface; and precipitation hardening the aluminum alloy backing plate to the fully hard T6 condition.

Preferably the master alloy is prepared by combining a major amount of high purity copper with a minor amount of at least one of the micro-alloy stabilizers Ag, Sn, Te, In, Mg, B, Bi, Sb, and P, melting the combination and casting to produce a master alloy.

In the preferred embodiment the master alloy is formed by combining high purity copper with at least one of the micro alloy stabilizers in a ratio of about 1,000 to 1.

The backing plate having a precladding surface of CuCr diffusion bonded thereto is preferably produced by a process comprising embedding an alloy of Cu and Cr in an aluminum or aluminum alloy envelope and e-beam welding the envelope closed in a vacuum environment; heat treating the enclosed envelope and forging to bring the CuCr into intimate contact with the aluminum alloy, and then heat treating to diffusion anneal and solutionize the hardening elements in the aluminum alloy, quenching and

thereafter removing the aluminum alloy envelope to expose the CuCr surface and precipitation harden the aluminum alloy to a fully hard T6 condition.

Sputtering targets in accordance with the invention may be used to produce an interconnect for use in an integrated circuit, having a width 0.18 microns or less and comprising copper of at least about 99.999 wt.% purity, preferably copper of at least about 99.9999 wt.% purity.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram showing the orientation of the deformation steps in the hot work breakdown of the cast copper billet;

FIG. 2 is a schematic flow diagram for diffusion bonding of a high purity copper target;

FIG. 3 is a photomicrograph of a cross section of a copper casting;

FIG. 4 is a diagram describing the sample locations on a Cu casting for an experimental matrix on deformation;

FIG. 5 is a schematic diagram describing the hot work breakdown deformation schedule;

FIG. 6 is a photomicrograph of a sample having been subjected to a 40% deformation;

FIG. 7 is a photomicrograph of a sample having been subjected to a 30% deformation;

FIG. 8 is a photomicrograph of a sample subjected to a 40% deformation, as shown in FIG. 6, and 70% frictionless forging

FIG. 9 is a photomicrograph of a sample subjected to 30% deformation, as shown in FIG. 7 and a 70% frictionless forging;

FIGS. 10 and 11 are photomicrographs of a Cu target, CuCr intermediate layer and an Al backing plate; and

FIG. 12 is a photomicrograph of a Cu target microstructure at 200 x magnification, showing grain size of about 30  $\mu\text{m}$ .

## DETAILED DESCRIPTION

As previously discussed, high purity copper, for example of  
5 at least 99.999 wt.% purity is especially useful for producing  
high purity copper interconnects for use in integrated circuits.  
Control of grain size and grain growth is very difficult for  
purity levels exceeding 99.999 wt.% and containing unalloyed  
material. Also, copper is particularly susceptible to anomalous  
10 grain growth effects, where a few grains scattered throughout the  
material grow considerably faster than the matrix. As the grains  
grow, they consume the smaller matrix grains until the entire  
structure ends up with a very large grain size, often in excess  
of 250  $\mu\text{m}$ . There is a critical temperature for the onset of  
15 anomalous grain growth but unfortunately the critical temperature  
is often above the minimum temperature needed for diffusion  
bonding.

It might be desirable to employ low diffusion bonding  
temperatures so as not to de-stabilize the target grain  
20 structure, but high purity copper does not possess the inherent  
temperature stability to survive these conditions and if used,  
result in a weak bond strength, i.e. less than 4,000 psi. Also,  
the use of a low temperature bonding techniques does nothing to  
stabilize the target microstructure during heat generated during  
25 the sputtering process.

It has been found that through use of selected alloying  
elements at ppm and sub-ppm levels, a high purity copper target  
microstructure can be stabilized sufficiently to allow diffusion  
bonding and prevent grain growth under high power sputtering  
30 conditions that generate a considerable amount of heat. However,  
controllably alloying to the ppm and sub-ppm levels is difficult.  
The present invention solves this problem by use of a master  
alloy with precise control of the amounts of micro-alloying  
stabilizers. The amounts of alloying elements are at  
35 sufficiently low levels as to not interfere with the bulk

1 34006/VGG/J104

resistivity of the copper. The stabilization of the structure provides some latitude in temperature parameters during diffusion bonding processes thereby permitting enough of a temperature window to provide a mechanically strong bond, e.g. greater than about 4,000 psi, with a high stiffness backing plate.

5 The thermal mechanical processing used to make the targets has a major affect on the final grain size and uniformity. The deformation process must be able to break up existing grains regardless of their size and orientation. Large deformation on all three axis of the casting billet is required. An incorrect deformation process yielding insufficient deformation will result in some of the as cast grain structure being retained in the final structure as larger grains that are partially or fully re-crystallized. Such large-grained areas can interfere with the sputtering performance of the target. Correct deformation procedures will result in a fine grain and substantially uniform structure in the target.

10 To produce a sputtering target assembly in accordance with the invention a high purity copper target is diffusion bonded to a precipitation hardened aluminum alloy backing plate by use of an intermediate CuCr interlayer between the high purity copper target and the aluminum backing plate. This provides a final bonded target assembly with several unique properties. Firstly, the grain size of the high purity copper target remains small, e.g. less than about 50  $\mu\text{m}$  and substantially uniform, i.e. with no anomalous grain growth. Secondly, the strength of the precipitation hardened backing plate is in the fully hard T6 condition, which is an important requirement for large, thin planar sputtering targets. This technique could be used with precipitation hardenable Al alloys, such as the 2000, 6000 or 7000 series alloys. It is also possible to achieve diffusion to a non-precipitation hardenable alloy, such as the 5000 series

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1 34006/VGG/J104

alloy, but the backing plate will not achieve a fully hard condition, with alloy 6061 being the most popular grade.

5 In addition to the CuCr alloy described, there are a number of commercial Cu alloys that could be used in this process. These alloys are included in the following:

Table 1

*UNS #	Copper/Copper Alloy Types
C10100 C10200 C10300	Oxygen-free coppers
C10400 C10500 C50700	Oxygen-free silver coppers
C10800	Oxygen-free low phosphorus copper
C11000	Electrolytic tough pitch coppers
C11300 C11400 C11500 C11600	Silver bearing, tough pitch coppers
C12500 C12700 C12800 C12900 C13000	Fine refined, tough pitch coppers with silver
C14300 C14310 C16200	Cadmium coppers
C14500 C18700	Free machining coppers
C14700	Sulfur copper
C15000	Zirconium copper
C17000 C17200 C17300 C17500 C17600	Beryllium coppers

*UNS #	Copper/Copper Alloy Types
C18200 C18400 C18500	Chromium coppers
C19200 C19400 C19500	High strength modified coppers
C60600	Aluminum bronze
C65100	Low silicon bronze

\* The Unified Numbering System (UNS) is the accepted alloy designation system in North America for wrought and cast copper alloy products. The three-digit system developed by the U.S. copper and brass industry was expanded to five digits following the prefix letter C and made part of the Unified Numbering System for Metals and Alloys. UNS designations are simply expansions of the former designations. For example, Copper Alloy No. 377 (forging brass) in the original three-digit system became C37700 in the UNS System. The UNS is managed jointly by the American Society for Testing and Materials and the Society of Automotive Engineers. Because these old numbers are embedded in the new UNS numbers, no confusion need result.

In one example of the method of producing a high purity sputtering target assembly in accordance with the invention, a high purity copper target of at least about 99.999 wt.% purity, preferably at least about 99.9999 wt.% purity, is provided. A high purity Cu target can be made by a casting process that includes consolidation of ultra-high purity, electro-refined copper cathode plate. The cathode plate is melted in order to allow residual chemicals from the refining process to be burned off. Surface moisture from the environment is also driven off during melting, and the melt is held at a high enough temperature to allow a majority of the gases and volatilizable material entrapped in the metal, such as oxygen and sulfur, to be driven from the metal. The metal is then allowed to solidify in the crucible.



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An important step in the copper casting process is to prepare a master alloy. Although there many alloying elements have the ability to raise the recrystallization temperature of pure copper, the required alloying level has been thought to be typically higher than 1000 ppm. However, in accordance with the present invention it has been found that significant increases in the recrystallization temperature can be achieved with lesser amounts of selected alloying elements, i.e. less than about 10 ppm, or even sub-ppm level additions, but the potential alloying elements must be chosen so as not to interfere with the resistivity of the metal. Alloying elements that meet this criteria include, but are not limited to, Ag, Sn, Te, In, Mg, B, Bi, Sb, and P. As an example, silver may be added in the range of about 0.3 ppm to 10 ppm to act as a stabilizer for the grain structure during diffusion bonding, while still allowing the Cu target to meet the minimum 99.999 wt.% purity grade specifications. A preferred amount of silver is about 2.5 ppm in this context. However, to make the master alloy with silver, or any of the other micro-alloy elements, care must be taken to avoid simply adding the pure form of the element to copper since this will result in a loss of significant amounts of the element due to the fact that their vapor pressure may exceed 1 atmosphere at the temperatures typically used for melting copper. Because the vapor pressure is high, the alloying addition, e.g. silver, would evaporate, making it difficult to control the ppm or sub-ppm level of the alloying additions. To precisely control the alloying level, a master alloy, e.g. with at least 100 ppm silver, is used. To make this master alloy a ratio of copper to alloying addition of about 1,000 to 1 is desirable. For example, 2000 grams of high purity copper cathode plate is melted with 2 grams of silver. The metal may be melted via induction heating in an open atmosphere. Once the metal becomes molten, the melt is cast into one-inch diameter billets. A sample of the billet

1 34006/VGG/J104

is cut and analyzed by the GDMS (Glow discharge mass spectrometer) analysis method. The small diameter billet of the master alloy can then be easily cut into convenient sizes for adding as alloying addition.

After the master alloy has been made, it can be combined in appropriate amounts with pure high purity copper to be melted to form a cast billet. This operation is advantageously conducted in a vacuum furnace in order to minimize the possibility of oxidation. The pre-consolidated cathode plate is weighed to provide an amount which will produce the desired billet size, then the master alloy is cut and weighed to the desired alloying level, e.g. 2.5 ppm silver. The pre-consolidated copper and master alloy is then placed in a melting crucible in a vacuum chamber. In the preferred embodiment the material will be heated until it reaches about 1200°C to melt at which temperature it is held for about ten minutes and then cooled to about 1038°C. The cycle is repeated two additional times to drive off any residual gas in the metal under vacuum environment. The metal is then heated to the casting temperature and poured into a graphite mold and cooled. The top 3 inches and bottom 2 inches may be cut from the cast billet to remove any shrinkage or solidification voids at the top of the billet and cold laps at the bottom of the billet. The billet is then ready for deformation.

The billet is deformed to remove the as-cast grain structure. This deformation step is referred to as the "hot work breakdown" of the billet.

Again in the preferred embodiment the billet is processed as follows: The billet is first heated to about 343°C. and then deformed for a total of 50% deformation on each of the 3 axes. FIG. 1 shows the orientation of the deformation steps and the hot work deformation schedule. The billet is water quenched after the sixth hot work breakdown step.

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1 34006/VGG/J104

The next step is frictionless forging. The billet is heated to about 343°C and forged in a friction free condition to 70% of the starting height using the same axis as the first hot work breakdown deformation step. The sample is then water quenched. Next, the material is cold rolled to give a total of 90% deformation (frictionless forge + cold roll). The material is then ready for diffusion bonding.

10 The process for diffusion bonding process is shown generally in Fig. 2.

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15 The first step in the diffusion bonding process involves the simultaneous diffusion bonding of the CuCr to the precipitation hardenable aluminum alloy and the solutionizing of the aluminum alloy. A thin alloy plate of copper with about 0.5 to 1.5 wt.% chromium is first embedded inside an envelope of aluminum alloy as shown in FIG. 2. This assembly is then e-beam welded shut in a vacuum environment. The sealed assembly can be removed from the vacuum environment and handled freely without fear of contamination or oxidation. The assembly is heated to 338°C, and the temperature is allowed to equilibrate for 30 minutes.

20 After 30 minutes at 338°C, the assembly is forged at 300°C to bring the CuCr and the aluminum alloy 6061 into intimate contact. The assembly is then quickly returned to the furnace for a 1-hour diffusion anneal at 338°C. After 1 hour at 338°C, the furnace temperature is then slowly ramped to 529°C and held at this temperature for 90 minutes to put all the hardening elements in the 6061 alloy into solution. This solutionizing step is followed immediately by a rapid quench, e.g. in water. Quenching is critical in order to retain the hardening elements in solution for subsequent precipitation hardening. Quenching differentiates this process from HIP or vacuum hot press processes, since quenching would not be possible in the latter two cases. After quenching, the cover of the assembly is machined off to expose the CuCr surface.

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The pre-clad backing plate is now ready for diffusion bonding to the Cu sputtering target blank. A cleaned Cu blank is stacked on the cleaned CuCr surface, and the stack is placed into a vacuum hot press where it is hot pressed under 8,500 psi of pressure at about 250°C and 300°C for 2 hours, and furnace cooled to room temperature. Several critical transformations in the target fabrication process occur during this step. First the Cu blank is recrystallized to form a fine grained, uniform and stable microstructure. Second, the diffusion bond is formed between the Cu blank and the CuCr interlayer. Finally, the 6061 aluminum alloy backing plate is precipitation hardened to the fully hard T6 condition.

The thermal mechanical processing used will have an affect on the final grain size and uniformity. Incorrect deformation procedure will result in some of the as cast grain structure being retained in the final structure as larger grains that are partially or fully re-crystallized. To elucidate the difference in final metallurgy between 30% and 40% deformation during the hot work breakdown steps an experimental matrix was established. Samples were chosen to ensure that a direct comparison would be possible between the two starting samples.

A cast billet is symmetrical about a vertical line running down the center of the billet, see Fig. 3. Two samples cut from the top of the ingot and hot work on each axis by different amount will result in different grain sizes. As shown in Fig. 4, Sample A and B are from a region of the casting where equiaxed largest grains are present. Sample A is hot worked to get 40% deformation on each axis; Sample B is hot worked by 30% on each axis. The hot work breakdown schedule is described in Fig. 5.

Samples, polished and etched, reveal that the microstructure of the 40% deformed sample was small grained and uniform. The 30% deformed sample has a non uniform grain structure, see Figs. 6 and 7, and Figs. 8 and 9.

1 34006/VGG/J104

As can be seen, the hot work samples that are rolled or forged in one direction will have a grain structure and size that is dependent on the as hot-worked grains. Microstructures of Samples A and B frictionless forged 70% in one direction as shown in Figures 6 and 7 are in the polished and etched state. The amount of deformation done during the hot work breakdown has an effect on final grain size, as indicated in the photomicrographs of Figures 8 and 9. Clearly, the grain size of Figure 8 is significantly finer. Figs. 10 and 11 show the assembly of a Cu target Al backing plate and intermediate CuCr interlayer. Fig. 12 shows the fine grain size of the high purity Cu target.

Recommended alloying elements include Ag, Sn, Te, In, Mg, B, Bi, Sb, and P. Silver is preferred to minimize the bulk resistivity of the material while maximizing the grain stabilization effect. Concentration range of the alloying elements are to a certain degree defined by grade. Recommended minimum and maximum concentrations are listed in Table 1. Below the minimum alloying levels, the grain structure fails to stabilize and anomalous grain growth can occur if the target is exposed to diffusion bonding temperatures. Above the maximum alloying levels, the material will no longer meet grade requirements for purity, if the micro-alloying element is considered in the total metallic impurities.

Table 2: Recommended Alloying Ranges in ppm by Weight

Grade	Minimum Alloying Level	Maximum Alloying Level
5N (99.999% pure)	0.3 ppm	10 ppm
5N5 (99.9995% pure)	0.3 ppm	5 ppm
6N (99.9999% pure)	0.3 ppm	1 ppm

The optimum ranges for deformation are generally defined by the amount of deformation required to achieve a uniform structure. For the hot work breakdown step of the Cu deformation process, the total strain after forging should advantageously be in the range of 2.14 and 5.49, corresponding to a 30% and a 60% forged height reduction per billet face. Below the minimum strain value, the structure may be insufficiently worked and the uniform grain structure may not be able to be achieved. There is risk that anomalous grains may result in the material due to insufficient deformation of isolated large grains that happen to be unfavorably oriented for slip during forging. Above the maximum strain value, buckling may occur. Material that is folded during buckling will produce a highly non-uniform structure and will form large voids within the material. Optimum deformation for the process employs a total strain of about 4.15, with an average of about 50% forged reduction per face.

Table 3: Optimum Compositions For Alloying With Ag:

Grade	Optimum Alloying Level
5N (99.9995% pure)	5+/-0.5 ppm
5N5 (99.9995% pure)	2.5 +/-0.25 ppm
6N (99.9999% pure)	0.5 +/-0.1 ppm

Total cold deformation after hot work breakdown, whether done by forging, rolling, an alternative deformation method, or some combination of various cold deformation techniques, should result in a total height reduction in the range of about 84% and 93%, with the optimum being about 90%. Below this range, sufficient grain refining may not occur and the final product grain size may be too large. Above this range, the excess strain

